Index-based Digital Texture Printing Workflow

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Abstract

Since digital printing technologies have matured to achieve robustness and consistency, the research development has gradually shifted to applying these printing technologies to an on-demand manufacturing process, i.e. functional printing, which offers various benefits over the traditional manufacturing process such as just-in-time and variable pattern fulfillment. This paper will describe an index-based digital texture printing workflow to accurately deposit one or multiple texture patterns selected from a list of predefined texture patterns at specified areas on a substrate such as paper or plastic/foil using the multilevel halftoning electrophotographic process and KODAK NEXPRESS Dimensional Clear Dry Ink.

Introduction

Digital printing technologies have matured to achieve robustness and consistency after extensive research effort in the past three decades. As a result, the research development has gradually shifted to applying these printing technologies to an on-demand manufacturing process such as functional printing, which offers various benefits over the traditional manufacturing process such as just-in-time and variable pattern fulfillment. While the actual chemistry and materials involved in each manufacturing process might be different, like digital printing, the basic objective of functional printing is to deposit requested image patterns on a receiver. The major difference is that, while the digital printing process only needs to reproduce the requested digital image within visually acceptable tolerance, the challenge for functional printing is to generate requested image patterns within manufacturing specifications, which could be much more stringent. As a result, it is essential for digital functional printing workflow to satisfy the following requirements:

1. No lossy image compression/decompression operation on the requested image patterns. Lossy compression is widely adopted to achieve high speed commercial printing in the conventional digital printing workflow.
2. Allow various image patterns to be deposited on a receiver, whose size and locations are specified in an input document.
3. Faithfully reproduce the requested patterns without being rendered by any halftone structure.

This paper focuses on the application of depositing one or multiple texture patterns selected from a set of predefined texture patterns at specified areas on a substrate such as paper or plastic/foil. This manufacturing capability will greatly increase the appearance variability of the printed surface without the need for carrying any inventory of those specialized substrates. Furthermore, this technology can also simulate different surface finishes on the same sheet of substrate. Recognizing that the normal digital halftone screen can also be treated as a set of predefine texture patterns with either amplitude-modulated or frequency-modulated structures, the proposed digital texture printing workflow modifies the halftone screen file to contain the predefined set of texture patterns [1]. One texture pattern can occupy one or multiple code values. As a result, instead of creating various intended texture patterns on the specified locations, which might suffer from texture degradation when passing through the RIP engine, a user only needs to generate an index image to identify the type of the intended texture pattern and its relative location on the receiver. This approach, denoted as *index-based digital texture printing workflow*, accomplishes three objectives [2, 3]:

1. Minimizes changes to the existing digital printing workflow.
2. Faithfully reproduce all texture patterns without compression artifacts and standard AM, FM, and/or error-diffusion halftone structures.
3. Fully control the deposition of texture types, locations and sizes by the index image.

Because the index image will be processed by a conventional digital printing workflow, the quality of the rendered image might be degraded by the usual lossy compression/decompression operation [4]. Therefore, if each code value is attributed to a texture pattern which is distinctively different from its immediate neighboring texture pattern, the compression artifact might result in undefined texture pattern along the edges in the index image. This error can be ameliorated by associating the same texture pattern to a range of code values and the index assignment directing to this specific texture pattern is their median code value.

While it is possible to implement this workflow using the threshold matrix halftoning operation, its inherent stacking constraint is too restrictive to allow texture patterns with arbitrary spatial and frequency features. The proposed workflow as shown in Figure 1 adopts the multilevel halftone processing system to encode the desired texture patterns inside the multilevel halftone screen [5]. Currently, seven different texture patterns as shown in Figure 2 are encoded for graphic designers and print service providers to manufacture various surface effects such as textile or Luster surface (e.g. *Eastman Kodak E Surface*), on standard paper substrate. There are two paths to enable the texture manufacturing process:

Image Mode Creates a separate index layer on the digital image to specify the type and the pixel locations of the desired texture pattern.

Global Mode Selects a desired texture pattern on the job ticket, and apply the texture effect on the entire printed area.

Because it is not necessary for the multilevel halftone screen to obey the stacking constraint, it is very easy to replace the existing texture pattern or add new texture pattern to fulfill new functional printing applications.

Index-based Texture Printing Workflow

It is necessary to develop sufficient height on the substrate to be perceivable by human beings. In this paper, the KODAK NEXPRESS printing system with Dimensional Clear Dry Ink is used to create texture patterns up to 28 microns height in one single pass. While the existing digital printing workflow can reproduce normal image content using the Dimensional Clear Dry Ink, texture patterns with higher frequency components are significantly degraded by the compression/descompression operation in the data ripping process, which, in turn, poses a serious challenge for manufacturing various surface finishes such as *E-Surface* on a standard paper substrate. Even if the printing workflow adopts a lossless compression scheme, the final printed image will still be rendered by a halftone pattern. As a result, unless the intended texture is a binary image with 0 and 1, the printed texture will be contaminated by the chosen halftone pattern. Furthermore, since the type of texture being printed is indexed at the pixel level, the boundary of each texture pattern is not confined to being rectangular. The regular gray scale halftone screen can be compressed into the multilevel texture screen structure, denoted as 'No Texture', which equips the proposed texture printing workflow to behave as a normal printing workflow to print any texture image with with reduced tonal resolution, for example, Variable Data Printing *(VDP)*.

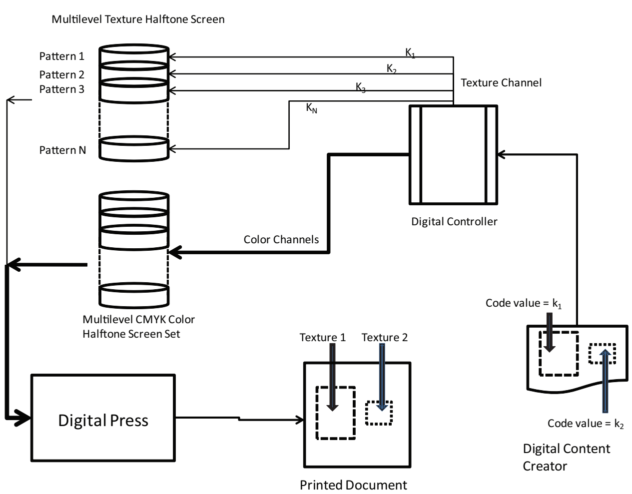

Figure 1. *Index-based Texture Assignment (Image Mode)*

Figure 1 shows how the Digital Front End, *DFE*, separately interprets the regular color channel layer and texture index layer through corresponding halftone screens, where all predefined texture patterns are embedded in the multilevel texture halftone screen. In the *Image Mode*, the input digital file contains a separate texture index layer, where pixels in the area intended to be simulated with texture K is coded with value between the minimal and maximal code value as listed in Table 1. In the *Global Mode*, the *DFE* automatically overlays the texture pattern over the entire printable area based on the request from the job ticket. This allows print providers to take advantage of this newly-offered texture surface manufacturing capability without modify their existing print jobs.

Table 1: Tint-to-Texture Selection Specification

Tint	Texture	Max CV	Min CV
0 %	No Texture	12	0
10 %	Texture 1	38	13
20 %	Texture 2	63	39
30 %	Texture 3	89	64
40 %	Texture 4	114	90
50 %	Texture 5	140	115
60 %	Texture 6	165	141
70 %	Texture 7	191	166
80 %	Texture 8	216	192
90 %	Texture 9	242	217
100 %	Texture 10	255	243

Predefined Texture Patterns

There are eight addressable texture patterns in the current implementation with two extra expandable slots as shown in Figure 2. They can be roughly classified into linen, mesh, and isotropic patterns with different spatial frequency ranges of dominant components to simulate various popular manufactured substrate surfaces, such as *E-Surface*, cloth and glossy finish. Although this multilevel texture halftone screen does not need to obey the stacking constraint throughout the tone scale, it is necessary for all texture patterns to be free of tiling artifacts.

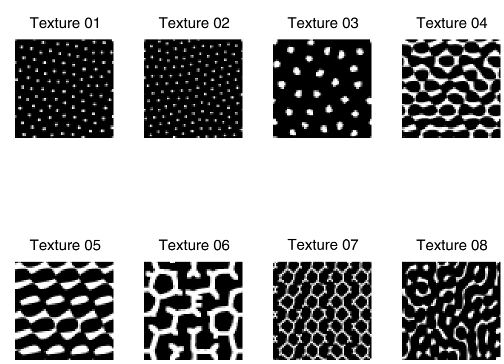

Figure 2. *Designed texture patterns*

Grey Level Printing and Multilevel Halftone

The proposed index-based digital texture printing workflow is enabled by the gray scale printing technology with LED printhead and multilevel halftone screen technologies [5, 6, 7, 8]. In the electrophotographic printing process, the resulted reflection density, $D(n)$, at specific LED pixel location, n, is nonlinearly proportional to the level of exposure,

$$E(i,n) = I(n) \times t(i,n), \tag{1}$$

where $I(n)$ is the light intensity at the corresponding LED and $t(i,n)$ is the duration of exposure time for tone scale i. Under the ideal condition of equal LED light intensity across the entire LED printhead, the relationship between $D(n)$ and $t(i,n)$ exhibits the well-known *S-Shape* characteristics as shown in Figure 3. Similar characteristic curves between the amount of exposure and reflection density occur in film and transparency with different gamma coefficients [9]. Gray scale printing can be achieved by precisely controlling the duration of exposure time at each pixel $n = 1 \cdots N$ and gradation level $i = 0 \cdots 255$ [7, 8]. This gray scale printing technology can resolve extremely fine difference in tonal scale as well as printing a line or curve structure to super resolution accuracy by modifying the level of exposure, $E(i,n)$, at the associated pixels.

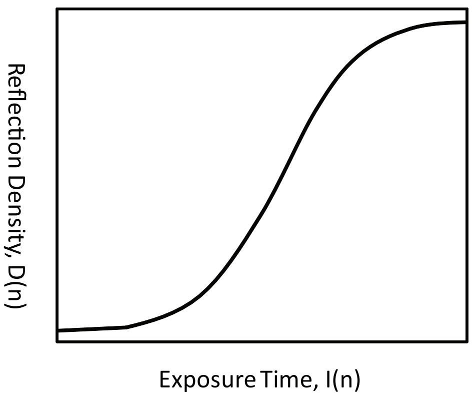

Figure 3. *Characteristic curve between the exposure time and reflection density*

The objective of using any halftone structure in gray scale printing is to provide stability in the printing process by gradually increasing/expanding the amount of exposure from the locations of predefined center points, which can form a periodic pattern with amplitude-modulation, *AM screen*, a stochastic pattern with frequency modulation, *FM screen*, or a hybrid pattern [5]. The printing process stability improves when the number of center points per unit area decreases, which can result in a more objectionable halftone screen structure. The traditional two-dimensional threshold matrix is unable to access intermediate exposure levels, which negate the effort of gray scale printing using the LED printhead. The multilevel halftone screen adopts a three dimensional tensor structure as shown in Figure 1 to specify the amount of exposure to form each halftone dot at every gradation level $i = 0 \cdots 255$. The design of a multilevel halftone screen set for traditional digital color printing needs to satisfy the following constraints:

1. No perceivable tiling or auto morié artifact for each individual color channel.
2. Minimal perceivable overprint morié artifact between any two or more color channels.
3. Smooth rendition with minimal perceivable contouring artifact throughout the entire tone scale gradation.

While the multilevel texture halftone screen still needs to satisfy the first and second constraint between the texture halftone screen and other color halftone screen, the smooth tone scale gradation requirement is replaced by an aesthetic requirement to simulate the intended surface finish, which are not currently modeled as a numerical optimization problem. Furthermore, even though natural texture patterns are often non-repeating, the size of the multilevel texture halftone screen is limited by maximum allowable physical memory size. As a result, the design of a texture halftone screen is an iterative process involving visual evaluation and continuously modifying pattern generating parameters.

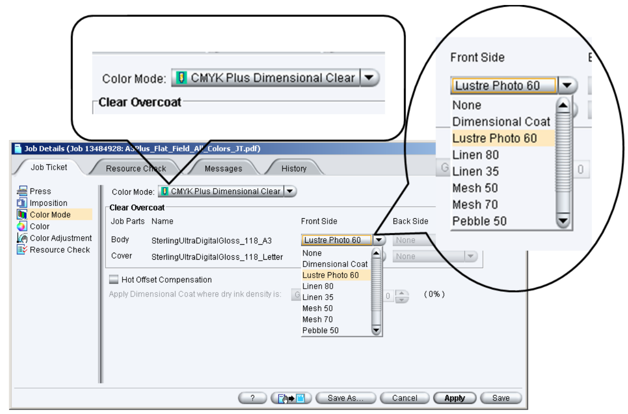

Figure 4. *Global Mode User Interface*

User Control Interface

Figure 4 and Figure 5 show the user interface for the Global Mode and the Image Mode on the Eastman Kodak NexPress five color digital printing press. The Dimensional Clear Dry Ink is enabled in the fifth color channel and the first four color channels are black, yellow, magenta and cyan respectively. As a result, the intended texture surface finish is formed on the top of regular color printed image. In the Global Mode, the print service provider can select a desired texture finish surface (such as Lustre Photo 60, Linen 80, Pebble 50, etc.) from the dropdown list. The numerical values indicate the dominant spatial frequency range. The higher the number, the more subtle the printed texture appears.

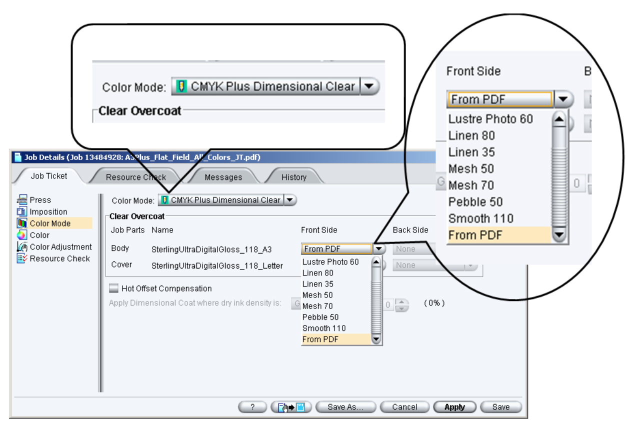

Figure 5. *Image Mode User Interface*

The Global mode is designed for a print job where no index-based Dimensional Clear layer exists. This will allow the print service provider to easily manufacture the desired texture surface finish on the existing four-color jobs. In the Image Mode, the user-interface option of *'From PDF'* needs to be selected to allow the index layer in the input PDF files to control the desired texture appearance at the specified locations on printed samples. As appears on both user-interface figures, the print service provider can choose a different mode for cover pages and body pages. Because extra effort is required for a graphic designer to create the texture index layer on the top of the existing layers, this option on the user interface will allow the graphic designer to concentrate on high value pages. By designating pages with Dimensional Clear texture index layer as cover pages, the proposed texture printing workflow can manufacture the desired texture patterns as requested while over-coating the remaining pages, denoted as body pages, with or without another texture finish.

Conclusion and Future Work

The index-based digital texture printing workflow is proposed to precisely deposit one or multiple predefined texture patterns on a receiver, and it is implemented on the Eastman Kodak NexPress printing press to simulate different surface finishes using the Dimensional Clear Dry Ink. Two printing modes are enabled: Image Mode and Global Mode. In the Image Mode, a separate texture index layer is added to each intended page and the corresponding texture pattern is deposited at the specified pixel locations. In the Global Mode, the print service provider can select a desired texture pattern from a drop-down list on the job ticket editor and the chosen substrate surface finish will be manufactured on all printed pages. While the Image Mode allows the graphic designers to precisely incorporate various texture surface finishes into their design upstream in the workflow, the Global Mode is more suitable for the final enhancement of simulating different surface finish on the existing print jobs. Seven texture surface finishes, denoted as Lustre Photo 60, Linen 80, Linen 35, Mesh 50, Mesh 70, Pebble 50, and Smooth 110, are released for graphic designers and print service providers to use.

The current multilevel texture halftone design is an iterative process with feedback from visual evaluation. In the future, we would like to extend to an algorithmic approach where a reference example of texture pattern and the maximal size of allowable halftone screen are provided. As a result, it is possible to derive the texture halftone screen by casting it as a numerical optimization problem, where the objective is to minimize the difference between the reference texture pattern and the concatenated texture halftone screen with no perceivable tiling and morié artifacts.

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